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**Mortality of Juvenile Atlantic Salmon
(Salmo salar) Exposed to Water Withdrawn
from the Hypolimnion of a Headpond on
the Mersey River, Nova Scotia**

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MORTALITY OF JUVENILE ATLANTIC SALMON (*SALMO SALAR*)
EXPOSED TO WATER WITHDRAWN FROM THE HYPOLIMNION
OF A HEADPOND ON THE MERSEY RIVER, NOVA SCOTIA

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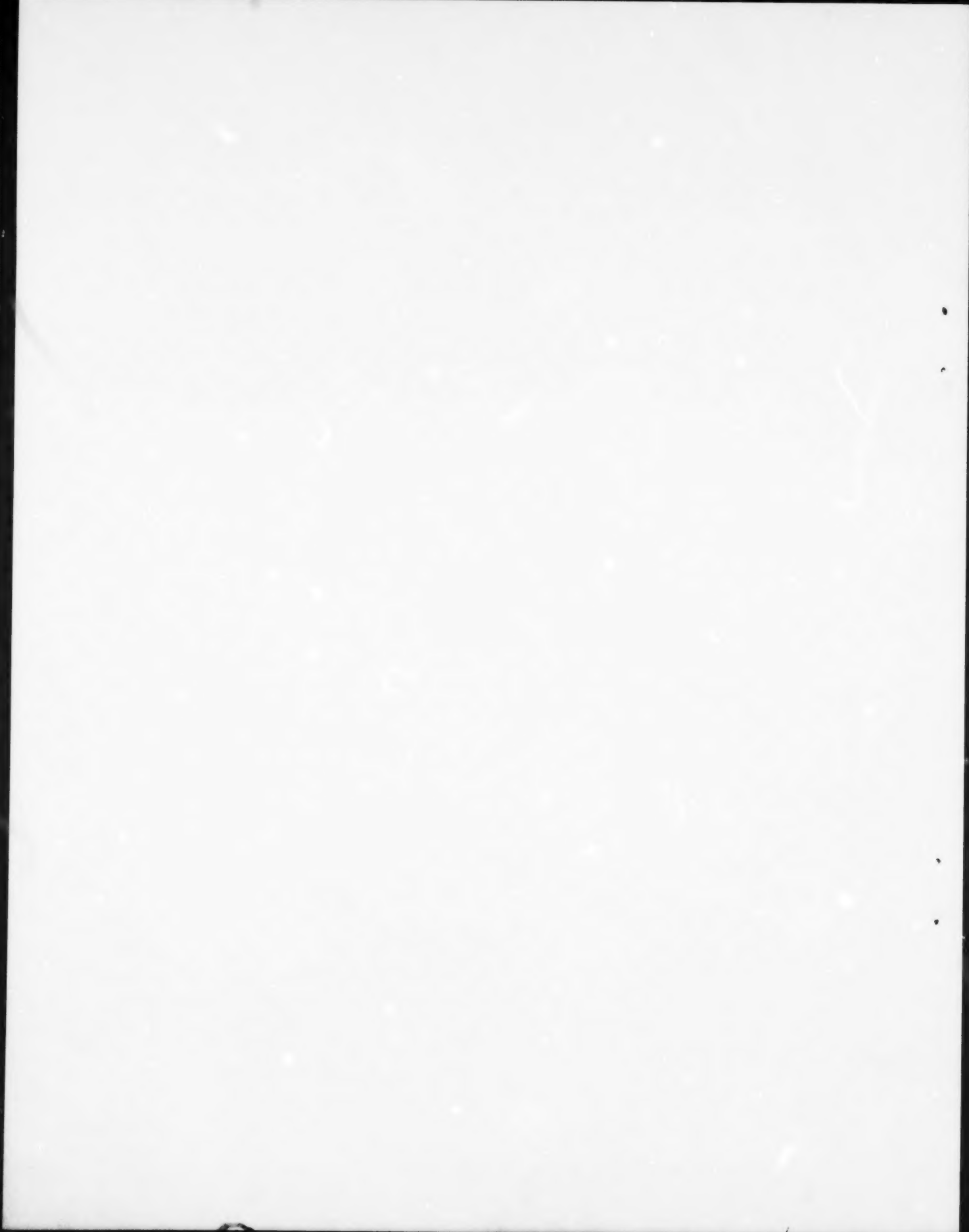
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ABSTRACT

Farmer, G.J., T.R. Goff and D. Ashfield. 1989. Mortality of juvenile Atlantic salmon (Salmo salar) exposed to water withdrawn from the hypolimnion of a headpond on the Mersey River, Nova Scotia. Can. MS Rep. Fish. Aquat. Sci. No. 2016. v + 8 p.

A mortality of 8.6% of the 683,340 juvenile Atlantic salmon (Salmo salar) at the Mersey Fish Culture Station occurred during 12-25 August 1988. The salmon parr had been provided with water withdrawn from a depth of 9 m near the bottom of a headpond located on the Mersey River, Nova Scotia. The water was dark brown, smelled of hydrogen sulphide and had a very low concentration of dissolved oxygen. In addition, a reddish-brown material was observed to accumulate in boxes of limestone gravel placed within the hatchery ponds to aerate and alter pH of the incoming water. The same material was observed to adhere to the gill filaments of moribund parr. We suggest that ferrous and manganous bicarbonates were released from the headpond bottom sediments. Release of these bicarbonates occurs under anoxic conditions in the presence of carbon dioxide and a reducing agent such as decomposing organic matter. Subsequent aeration of the water containing ferrous and manganous bicarbonates resulted in the formation of ferric and manganic hydroxides which are insoluble precipitates. Accumulation of ferric and possibly manganic hydroxide on the gill filaments of the salmon parr appeared to cause an impairment of respiratory function which resulted in mortality. Concentrations of hydrogen sulphide in the water supply may also have contributed to the mortality of parr which occurred.

Key words: Atlantic salmon, salmon culture, Nova Scotia, water chemistry, ferric hydroxide, respiratory impairment.

RÉSUMÉ

Farmer, G.J., T.R. Goff and D. Ashfield. 1989. Mortality of juvenile Atlantic salmon (Salmo salar) exposed to water withdrawn from the hypolimnion of a headpond on the Mersey River, Nova Scotia. Can. MS Rep. Fish. Aquat. Sci. No. 2016. v + 8 p.

Du 12 au 25 août 1988, on a connu une mortalité de 8,6 p. 100 parmi les 683 340 saumons de l'Atlantique (Salmo salar) juvéniles de la pisciculture de Mersey. On avait alimenté les bassins de tacons d'une eau prélevée à une profondeur de neuf mètres, près du fond d'un bassin d'amont se trouvant sur la rivière Mersey (Nouvelle-Écosse). L'eau était de couleur brun foncé, sentait l'hydrogène sulfuré et possédait une très faible teneur en oxygène dissous. De plus, on a noté la présence d'une matière d'un brun rougeâtre dans des boîtes de gravier calcaire placées dans les bassins d'élevage dans le but d'aérer matière adhérait aux fibres des branchies des tacons morts. Nous sommes d'avis que des bicarbonates ferreux et manganoux se sont dégagés des sédiments du bassin d'amont. Un tel phénomène se produit en situation d'anoxie, en présence d'oxyde de carbone et d'un agent réducteur comme de la matière organique en décomposition. L'aération subséquente de l'eau contenant ces bicarbonates ferreux et manganoux a abouti à la formation d'hydroxyde ferrique et manganique, qui sont des précipités insolubles. La présence d'hydroxyde ferrique, peut-être même d'hydroxyde manganique, dans les fibres des branchies des tacons semble avoir causé une détérioration de la fonction respiratoire aboutissant à la mort. Il se peut également que la présence d'hydrogène sulfuré dans l'eau ait contribué à la mortalité.

Mots-clés: saumon de l'Atlantique, salmoniculture, Nouvelle-Écosse, eau, chimie, hydroxyde ferrique, détérioration de la fonction respiratoire.



INTRODUCTION

The Mersey Fish Culture Station is located on the Mersey River which drains to the southwest coast of Nova Scotia. The station has 7.6 and 11 m Swedish-type ponds and annual production is 300,000 one-year-old Atlantic salmon (*Salmo salar*) smolts. A series of dams have been constructed on the river for hydroelectric purposes. Water is withdrawn from the Big Falls headpond by means of dual 60 cm diameter polyethylene intakes and delivered to the station in a 30 cm diameter polyethylene pipeline. One of the intakes is located at a water depth of 2 m and the other on the bottom of the headpond at a depth of 9 m. Because the headpond surface temperature ranges from 22-27°C during the summer, cooler water is withdrawn from a depth of 9 m and provided to the salmon from mid-June to early September.

Like a number of rivers which drain to the Atlantic coast of Nova Scotia, the Mersey River is acidic, dark brown in colour, lacks acid-neutralizing capacity, has a low calcium concentration and an elevated concentration of total dissolved aluminum (Farmer et al. 1980, 1989). Prior to 1979, up to 38% of the salmon fry at the station died each year during the first month of feeding (Farmer et al. 1980) and 1-5% of the presmolts died during the winter (Goff et al. 1982). These mortalities were eliminated by treating the water with limestone gravel (CaCO_3) to alter pH and calcium concentration. Organic, rather than inorganic aluminum is the dominant form of aluminum in acidic, brown-coloured, Nova Scotia rivers and high hydrogen ion concentration is the primary lethal factor (Lacroix and Townsend 1987).

Salmon parr were exposed to water withdrawn from the bottom of the Big Falls headpond from mid-June 1988 until mortalities began to occur on 12 August. At that time, increasing volumes of surface water were mixed with the bottom water so that by 25 August only surface water was provided to the parr. This report describes the attempts made to determine the cause of the mortalities.

MATERIALS AND METHODS

Water samples were collected from various depths of the headpond in close proximity to the surface and deep intakes in a Kemmerer water sampling bottle and from the pipes which supply the 7.6 m ponds. Water samples for the determination of pH, apparent colour and identification of algal species were collected in 500-mL polyethylene containers which had been washed with laboratory detergent and then rinsed with deionized water. Samples for the determination of total calcium, magnesium, iron, manganese and aluminum concentrations were collected in 250-mL polyethylene containers which had been washed in a 50% HNO_3 solution and then rinsed with deionized water. These samples were preserved by adding one mL of 50% HNO_3 solution. Apparent colour was measured with a Helige Aqua Tester and pH within 24 h of sampling with a Metrohm Herisau pH meter. Concentrations of metals were determined by use of an emission spectrophotometer (Jarrel-Ash, AtomComp). Temperatures and dissolved oxygen concentrations in the ponds and at various depths in the headpond were determined with a YSI oxygen meter equipped with a 15 m cable

and submersible stirrer.

RESULTS

Mortality of salmon parr began 12 August and continued until 25 August. Prior to this period, the parr had been receiving water withdrawn from a depth of about 9 m near the bottom of the Big Falls headpond. During late July, there was a noticeable deterioration in the quality of the bottom water following a period of heavy rainfall (122.2 mm; 21-25 July). The bottom water became darker brown, smelled of hydrogen sulphide and had a very low concentration of dissolved oxygen. In addition, a reddish-brown material accumulated in the boxes of limestone gravel located within the 7.6 m ponds to aerate and alter the pH of the incoming acidic water. Dissolved oxygen concentration of the water which entered the 7.6 m ponds after percolation through the gravel ranged from 6.5 - 7.0 mg/L (about 89% saturation). Surface water was subsequently mixed with the bottom water during the 12-25 August period so that by 25 August only surface water (2 m depth) was supplied to the parr. Total mortality during the 12-25 August period was 8.6% of the 683,340 parr present at the beginning of that period (Table 1). Mortality was greater (18.8%) among parr in the 7.6 m ponds which receive first-use water than among parr in the 11 m ponds (2.8%) which are located at a lower elevation and receive water from the 7.6 m ponds. Mortality rate among parr in the 7.6 m ponds was quite variable and ranged from 4.9 - 38.7%. A reddish-brown material adhering to the gill filaments of moribund parr was evident upon microscopic examination. Neither parasites nor bacterial or viral pathogens were found among parr submitted to the Fish Health Service Unit for examination (File 88/08/26BZ).

Water samples collected 17 August indicated that dissolved oxygen concentration was 7.4 mg/L from the surface of the headpond to a depth of 6 m and that oxygen concentration declined to 0.5 mg/L at 7 m and to 0.2 mg/L at 9 m (Table 2). Apparent colour was 65 relative units from the surface to a depth of 6 m and then increased to 220 units at 9 m. Concentrations of iron and manganese in water collected from a depth of 9 m on 15 and 17 August were two to three times greater than measured in the mixture of surface and bottom water supplied to the parr at that time. The concentration of iron in water from a depth of 9 m measured 4.01 mg/L on 15 August and 4.405 mg/L on 17 August. Concentrations of manganese on those dates were 0.230 and 0.260 mg/L. Previous measurements of iron and manganese for the Mersey River ranged from 0.14-0.68 and 0.05-0.07 mg/L, respectively (Farmer et al. 1980). Water collected from a depth of 9 m on 13 September when the surface water temperature had declined and the headpond undergone mixing had reduced concentrations of iron and manganese of 0.500 and 0.090 mg/L, respectively. These concentrations were similar to those measured in surface water on that date. Concentrations of calcium, magnesium and aluminum in water collected from a depth of 2 m on 15, 17 August and 13 September were similar to concentrations in water from 9 m and not different than those that have been

¹ Department of Fisheries and Oceans, Biological Sciences Branch, Box 550, Halifax, N.S., B3J 2S7.

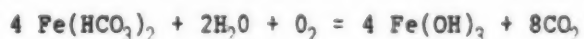
previously measured at the station (Farmer et al. 1980; Lacroix and Townsend 1987; Farmer et al. 1989). Water collected from a depth of 9 m smelled of hydrogen sulphide a few weeks prior to and during the 12-25 August period but not on 13 September after mixing of the headpond had occurred.

Limestone gravel used to alter the pH of water withdrawn from a depth of 9 m became coated with a reddish-brown material and required cleaning. This was done by spraying the gravel with water from a high pressure hose. The effluent was initially allowed to enter the ponds but was later diverted to a ditch. Concentrations of iron, manganese and aluminum in the effluent measured 10.0, 0.228 and 0.333 mg/L, respectively. The reddish-brown material also accumulated on the inner diameter of the pipes which supplied water to the 11 m ponds. Concentrations of iron, manganese and aluminum in a 5% solution of this material were 116.0, 0.520 and 2.0 mg/L, respectively.

Diatoms were the most common alga in water collected near the deep intake. The following genera and species were identified: Turbellaria fenestrata, Meridion circulare, Fragilaria crotonensis, Gyrosigma sp., Asterionella formosa, Amphora sp., Pachycladon umbrinitus, and Striatella interrupta (S.R. Durvasula, pers. comm.). Also observed was the blue-green alga Merismopedia sp. as well as unidentified bacteria and protozoans.

DISCUSSION

Iron and manganese have similar chemical properties and their distribution in the aquatic environment is related to concentrations of carbon dioxide and oxygen (Ruttner 1963). Iron can be bi-valent or tri-valent as the ferrous or ferric form. The ferrous form only exists in the absence of oxygen and the ferric form is insoluble (Ruttner 1963). Ferrous and manganous ions are released from the sediments as bicarbonates under anoxic conditions in the presence of carbon dioxide and a reducing agent such as decomposing organic matter (Ruttner 1963; Wetzel 1975). At neutrality, Einsele (1940; cited in Ruttner 1963) observed that a solution of ferrous bicarbonate can only exist when the water contains no more than 0.5 mg/L of oxygen. If oxygen is present, oxidation to insoluble ferric hydroxide takes place:



As oxygen concentration in the area of the deep hatchery intake decreased to ≤ 0.5 mg/L, there was undoubtedly a corresponding increase in carbon dioxide as a result of decomposition processes. These conditions favoured the reduction of ferric and manganic hydroxides in the sediments and their release as soluble ferrous and manganous bicarbonates. Concentrations of iron and manganese measured near the deep intake on 15 and 17 August were respectively 8-9 and 2-3 times greater than observed 13 September after

¹ S.R. Durvasula. 1988. Department of Fisheries and Oceans, Biological Sciences Branch, Box 1006, Dartmouth, N.S., B2Y 4A2.

headpond mixing had occurred. Water which contained ferrous and manganous bicarbonates was withdrawn by means of the deep intake and delivered to the 7.6 m ponds where it was aerated and treated with limestone to alter pH. We suggest that this caused the formation of ferric and manganic hydroxides which are insoluble precipitates that adhered to the gill filaments of the parr and resulted in mortality. These precipitates can form a tenacious film which seriously limits respiratory function (Daily and Economon 1983).

Concentrations of iron and manganese which appeared to cause mortality of juvenile salmon ranged from 4.01 - 4.405 and 0.23 - 0.26 mg/L, respectively. However, effluent created when the gravel was cleaned initially entered the 7.6 m ponds and had an iron concentration of 10 mg/L. Water quality standards established for fish culture purposes recommend that concentrations of iron and manganese be <0.1 and <0.01 mg/L, respectively (Daily and Economon 1983). Shepherd (1984) and the EPA (1973) suggest that the maximum acceptable concentrations of iron and manganese for fish are 0.3 and 0.1 mg/L, respectively. Smith and Sykora (1976) found that the safe, upper limit of lime-neutralized suspended iron for the hatchability, survival and growth of coho salmon alevins (Oncorhynchus kisutch) was within the range 0.97-1.27 mg Fe/L. Concentrations of iron and manganese not harmful to aquatic life in the Mersey River are somewhat greater than indicated by some of these standards. For example, concentrations of iron and manganese on 13 September ranged from 0.5 - 0.8 and 0.09 - 0.10 mg/L, respectively and were not harmful to the salmon. Such relatively high concentrations of iron are found in brown waters such as those of the Mersey River because the humic acids which are present form colloiddally dissolved humates with iron (Ruttner 1963). These organic iron sols are more stable than the inorganic bicarbonate solutions and humic waters usually contain considerable amounts of iron in the presence of oxygen.

Concentrations of total dissolved aluminum in the Big Falls headpond at a depth of 9 m on 15 and 17 August ranged from 0.253 - 0.330 mg/L and were no greater than concentrations which have been recorded for other brown, acidic, Nova Scotia rivers (Lacroix and Townsend 1987; Farmer et al. 1988). Lacroix and Townsend (1987) have shown that concentrations of toxic, inorganic aluminum in these rivers represent less than 10% of the total dissolved aluminum present and that this metal is not associated with the mortality of juvenile salmon. Increased hydrogen ion concentration is considered to be the primary lethal factor affecting juvenile salmon in these rivers which are rich in organic matter.

Hydrogen sulphide results from the bacterial reduction of sulphate and is only stable in the absence of oxygen (Ruttner 1963). Although the odour of hydrogen sulphide was apparent in water withdrawn from a depth of 9 m during August, the concentration was not measured and it is not known if undissociated H_2S was involved in the mortality of parr which occurred. Daily and Economon (1983) suggest that concentrations of H_2S in water used for fish culture purposes be <0.003 mg/L.

Depletion of oxygen in the area of the deep intake had not been observed prior to August, 1988. The lowest concentration of dissolved oxygen

previously measured was 3.5 mg/L. Oxygen depletion in the hypolimnion results from oxidation processes taking place in the water as well as in the contact zone between the ooze and water (Ruttner 1963). The most important of these processes are usually the bacterial and enzymatic breakdown of organic matter which originates in the phototrophic zone and the respiration of organisms. Oxygen consumption in the hypolimnion is influenced by temperature (Ruttner 1963). Thus, the rate is doubled or trebled by a temperature rise of 10°C. The hypolimnion in the Big Falls headpond was represented by a 1-2 m layer of water which had a temperature of about 18°C. This would favour the rapid oxidation of organic matter and depletion of dissolved oxygen content. The organic matter which reached the hypolimnion during the summer of 1988 may have resulted from an increase in primary productivity that year. In addition, organic matter from bog drainage may have been introduced during the period of heavy precipitation which occurred late in July. Diatoms were observed on the gill filaments of moribund parr. However, it is not believed they were responsible for the respiratory impairment which occurred but rather were involved in oxygen depletion of the hypolimnion.

When circulation begins in the autumn and oxygen is introduced into the deeper water upon breakdown of thermal stratification, ferric and manganic hydroxides settle to the bottom before they are transferred to the upper strata (Ruttner 1963). Thus, there is no significant loss of iron or manganese from the headpond outlet. This was apparent from the water samples collected 13 September after water temperature had decreased and circulation within the headpond had begun. Thus, the concentration of iron (0.50 mg/L) in water collected from a depth of 9 m was similar to that measured in surface water on that date but much lower than concentrations (4.010-4.405 mg/L) in water collected from 9 m on 15 and 17 August.

Cooler water was only available during the summer at depths of 7-9 m where dissolved oxygen concentrations were 0.2-0.5 mg/L and levels of hydrogen sulphide, iron and manganese were elevated. If the oxygen concentration of water withdrawn from that depth declines substantially in future, a decision will be made to primarily provide surface water to the salmon. Because the temperature of surface water will be 22-27°C during July and August, some reduction in food intake and growth can be expected but death resulting from exposure to hydrogen sulphide and/or ferric and manganic hydroxides can be avoided. Withdrawal of water from the hypolimnion of lakes or headponds for fish culture purposes should be avoided if anoxic conditions are known to exist.

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Table 1. Mortality of 0+ parr in the 7.6 m (upper) and 11 m (lower) ponds at the Mersey Fish Culture Station during the 12-25 August 1988 period.

Stock	Number of salmon, August 11	% Mortality, August 12-25	Pond size, m
Medway River (Harmony Mills)	29,980	38.7	7.6
Medway River (Ponhook Lake)	53,190	17.0	7.6
East River	24,900	15.2	7.6
Gold River	43,290	4.9	7.6
Moser River	21,900	28.0	7.6
Saint John River	39,150	23.7	7.6
Grand River	18,120	7.3	7.6
River Philip	15,390	15.0	7.6
LaHave River (salmon x salmon)	243,750	3.1	7.6 and 11
LaHave River (salmon x grilse)	69,650	0.9	11
Liscomb River	59,800	0.1	11
Musquodoboit River	64,220	7.3	11

Table 2. Chemical characteristics of water collected at various depths of the Big Falls headpond during the 15 August - 13 September 1988 period.

Depth (m)	Temperature (°C)	pH	Dissolved oxygen (mg/L)	Apparent colour (relative units)	Ca	Mg	Fe (mg/L)	Mn	Al
<u>August 15</u>									
9 (deep intake)					0.616	0.404	4.010	0.230	0.253
2+9 (mixture from surface & deep intakes)		5.65			0.538	0.340	1.645	0.112	0.145
<u>August 17</u>									
surface	24.0		7.4	65					
1	24.0		7.4						
2	24.0		7.4						
3	24.0		7.4						
4	24.0		7.4						
5	24.0		7.4						
6	24.0		7.4	65					
7	20.9		0.5	110					
8	17.8		0.3	200					
9	16.8		0.2	220	0.650	0.442	4.405	0.260	0.330
<u>September 13</u>									
2 (surface intake)	17.5 ¹	5.21			0.590	0.420	0.820	0.100	0.150
9 (deep intake)	17.5 ¹	5.22			0.620	0.420	0.500	0.090	0.160

¹ Estimated from temperature records for previous years.